High-J CO line emission from young stellar objects: from ISO to FIRST

Conference or Workshop Item

HIGH-J CO LINE EMISSION FROM YOUNG STELLAR OBJECTS: FROM ISO TO FIRST

B. Nisini[1], P. Saraceno[1]
C. Ceccarelli[1,2], T. Giannini[1], S. Molinari[1,3], E. Tommasi[3], L. Spinoglio[1] , G.J. White[4]

[1]CNR-Istituto di Fisica Spazio Interplanetario, I-00044 Frascati, Italy
[2]Observatoire de Grenoble - BP 53, F-38041 Grenoble cedex, France
[3]LIDT, ISO Science Operations Centre - P.O. Box 50727, 28080 Madrid, Spain
[4]Queen Mary & Westfield College, Mile End Road - London E1 4NS, UK

ABSTRACT

We present the CO pure rotational spectrum at high J (J_{up} >14) obtained with the Long Wavelength Spectrometer (LWS) on board of the ISO satellite towards molecular outflows exciting sources in nearby star formation regions. The physical conditions, derived using an LVG model for the line emission, indicate the presence of warm and dense gas, probably shock excited. The model fits show that often the bulk of this CO emission is expected in the spectral range that will be covered by FIRST, indicating the potentiality of this satellite to trace the warm component of gas emission in young stellar objects.

1. INTRODUCTION

Line emission from carbon monoxide is one of the main diagnostic tools used to investigate the physical properties of star forming regions. Given its high abundance and large dissociation energy, it can be excited in a variety of different physical environments; moreover, its spectrum spans from the near-IR to the millimeter probing a wide range of temperatures and densities.

Low-J rotational transitions of CO and its isotopes, which are easily excited even at very low temperatures, have been extensively used to detect and map outflowing molecular gas in Young Stellar Objects (YSOs), which can extend to more than 10^5 A.U. from the driving source. The CO transitions at higher J probe warmer (T>100K) and more compact gas arising mainly from the shocked regions where the collimated wind (or jet) from the source interacts with the ambient medium. These transitions could in principle also be excited in Photo-Dominated Regions (PDRs) created by the presence of diffuse FUV fields or they could be originated in collapsing envelopes surrounding protostars [Ref.1].

Here we report the results obtained with the ISO-LWS spectrometer [Ref.2,3] on the CO pure rotational spectrum at high J (J_{up} >14) towards four YSOs driving energetic mass flows. The LWS observations can be effectively used to give a gross estimate of the physical conditions of the emitting gas and to infer the possible origin of this emission; however, we show here how FIRST, given its complementary spectral coverage and higher spatial and spectral resolution, will be essential to obtain the additional information needed to model in detail the warm CO emission component.

2. ISO-LWS OBSERVATIONS

We consider here the FIR CO spectrum of four outflow exciting sources, namely B335 FIR, IRAS16293-2422, IC1396 N, and R CrA. Full LWS grating scans (43-193 μm) have been obtained for all the objects at spectral resolution ranging from R = 200 to 300, and with a FOV of ~80". In all the sources we observe at least four CO rotational lines, from J_{up} = 15 to J_{up} = 18; IC1396 N shows the richest spectrum, with lines detected up to J_{up} = 26. In addition to the CO rotational lines, [OI]63μm emission is observed in all the sources; in IC1396 N and IRAS16293-2422, also H_2O and OH rotational lines have been detected. A detailed description of the observations and results obtained for each source is given in Ref. [4,5,6,7], respectively.

3. CO LINE EMISSION FITTING

The CO data have been modelled by using a large velocity gradient (LVG) code in the plane-parallel geometry. Collisional downward rates for levels $< J_{up}$ =60 and T> 100 K were calculated using the γ_{J0} coefficients taken from Ref. [8] . Upwards rates are computed using the principle of detailed balance. Radiative decays rates were taken from Ref.[9]. The model depends on several free-parameters (gas kinetic temperature, density, intrinsic linewidth, CO column density and filling-factor), some of them related together. The procedure adopted to fit the data and obtain the pysical parameters is the following: having fixed the linewidth, which we usually take from the maximum velocity observed in the extended CO outflows, the shape of the observed CO emission distribution as a function of J_{up} is used to constrain the gas temperature and density and to define if the lines are optically thick. The absolute flux level is dependent on both the CO column density and the beam filling factor: if the lines turn to be optically thick, the derived optical depth can be used to constrain the column density and, consequently, the absolute flux gives us the size of

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the emitting gas. We stress that it is not always possible to uniquely define a model only with the LWS data, but usually a range of possible parameters is given. In the following we describe what we find for each source specifically addressing this point.

3.1. IRAS16293-2422

IRAS16293-2422 is a very young and highly obscured source (Class 0) situated in the ρ Ophiuchus complex at a distance of 160pc. This IRAS source is actually a close binary system whose two components are driving two separated and almost perpendicular molecular outflows. LWS have detected CO emission from J_{up} =14 to J_{up} =21: in addition, also the CO 6-5 transition has been observed and mapped from ground [Ref.10]. In fig.1a two extreme model fits are considered. The dashed line shows a model with T=450 K and $n_{H_2} = 5\times10^5$ cm^{-3}, which would give the best fit choice considering only the LWS data. On the other hand, a much different fit, also consistent with the LWS data, is obtained if we assume that the CO 6-5 emission comes from the same gas emitting at longer wavelengths, (continuum line in fig.1a). This model gives a temperature of 1200 K and a density of 3×10^4 cm^{-3}: moreover, from the extent of the emission that can be derived from the CO 6-5 map (about 14"×80") also the CO column density can be constrained (2×10^{16} cm^{-2}). It appears clear from the figure that observations of the CO transitions from J_{up} =6 to J_{up} =13 would be fundamental to finally discriminate between the two possible models.

3.2. B335 FIR

B335 FIR is a very young (Class 0) and embedded far-IR/millimeter source (L=3 $L_{\odot}$) situated at the center of a Bok globule (D=250pc) and driving a collimated outflow almost perpendicular to the line of sight. We observe only four CO transitions in this weak source, but the upper limits we are able to set for the J_{up} =19 and 20, together with the fact that we seem to observe the peak of this CO emission component, enable us to limit the range of the possible parameters. In fig.1b the two fits displayed represent the two extreme models which match the LWS observations: T=150 K, $n_{H_2} = 3\times10^6$ cm^{-3} (continuum line) and T=800 K, $n_{H_2} = 5\times10^5$ cm^{-3} (dashed line). The colder model produces slightly thick lines, implying a CO column density of about 4×10^{18} cm^{-2} and a size of the emitting region of about 2". The 6-5 emission has been also observed [Ref.10], but, in this case it is impossible to find a single component model fitting simultaneously the high-J and the low-J emission. Different emission components or a gradient in the density and temperature distribution of the emitting gas need to be taken into account. This can be effectively done only with a better coverage of the CO emission distribution as a function of J and with high spectral resolution observations allowing to discriminate different gas velocity components.

3.3. IC1396 N

IC1396 N is a bright rimmed globule associated with an IRAS source of about 200 $L_{\odot}$ (a Class I source at D = 750pc), located inside the HII region produced by a 16pc distant O6 star. The LWS spectrum of this source is particulary rich of bright molecular line emission [Ref.6]: the warm CO component is here traced up to J_{up} =26. Despite the high number of detected CO lines, also in this case we are not able to uniquely define nor even the temperature and density, since we cannot clearly identify at which J there is the distribution peak. The figure shows how the same lines can be originated by two components peaking at different J_{up} . We note also that the lines are always optically thin, and we are therefore unable to derive the CO column density without having an indipendent measure of the size of the emitting region.

3.4. R CrA

R CrA is a source more evolved (Class II) then the previously considered objects, being an Herbig Ae/Be stars still powering a relatively energetic molecular outflow. As in the case of B335, we observe only few CO transitions but they seem to trace the peak of the distribution allowing to give at least a gross estimate of density and temperature (T=350 ÷ 850 K with $n_{H_2} = 2\times10^6 \div 5\times10^5$ cm^{-3} respectively). A CO column density of 6×10^{18} cm^{-2} and an emitting size of about 6" are derived for the low-temperature model.

4. DISCUSSION

Since we are considering sources driving molecular outflows, the most natural origin for the emission of the warm and dense gas we are tracing with LWS is shock excited emission.
Contribution by PDR emission is very unlikely due to the low UV fields expected in the surrounding of these sources; also emission from accretion envelopes cannot dominates the observed line fluxes, given the relatively low-luminosity of the considered objects.
As regard to the type of shock producing the high-J CO lines, in all the considered cases there is evidence to favour a non-dissociative C-type shock [Ref.11] rather than a J-type shock [Ref. 12] (see the relative discussions in [Ref. 4,5,6,7]. This interpretation is in particular supported by the fact that the total luminosity of the CO lines is always larger than the luminosity of the [OI]63μm line observed in the same objects; indeed, J-shocks models predict that [OI] is the main coolant of the shock while in C-shocks the molecular emission always dominates. Moreover, the gas temperatures derived by the fits are always consistent with C-shock models (e.g. [Ref. 13]) with velocities ranging from 10 to 25 km s^{-1}. The occurrence of non-dissociative shocks along molecular outflows has been proven through observations of near-infrared transitions of H_2, which are suggested to be excited in curved shocks ("bow" shocks) produced at the head of the source jet or collimated wind, when this plouhgs into the ambient medium [Ref. 14]. The warm CO we are here considering may come from the same type of interaction (being CO one of the main coolant in C-shocks together with H_2); since in the FIR we are not limited by the extinction, we can trace shock emission around objects so deeply embedded that even the observations of near-infrared transitions are impossible.
We stress however that CO emission having a different origin could be superimposed at the observed shock component; this possibility cannot be disregarded specially

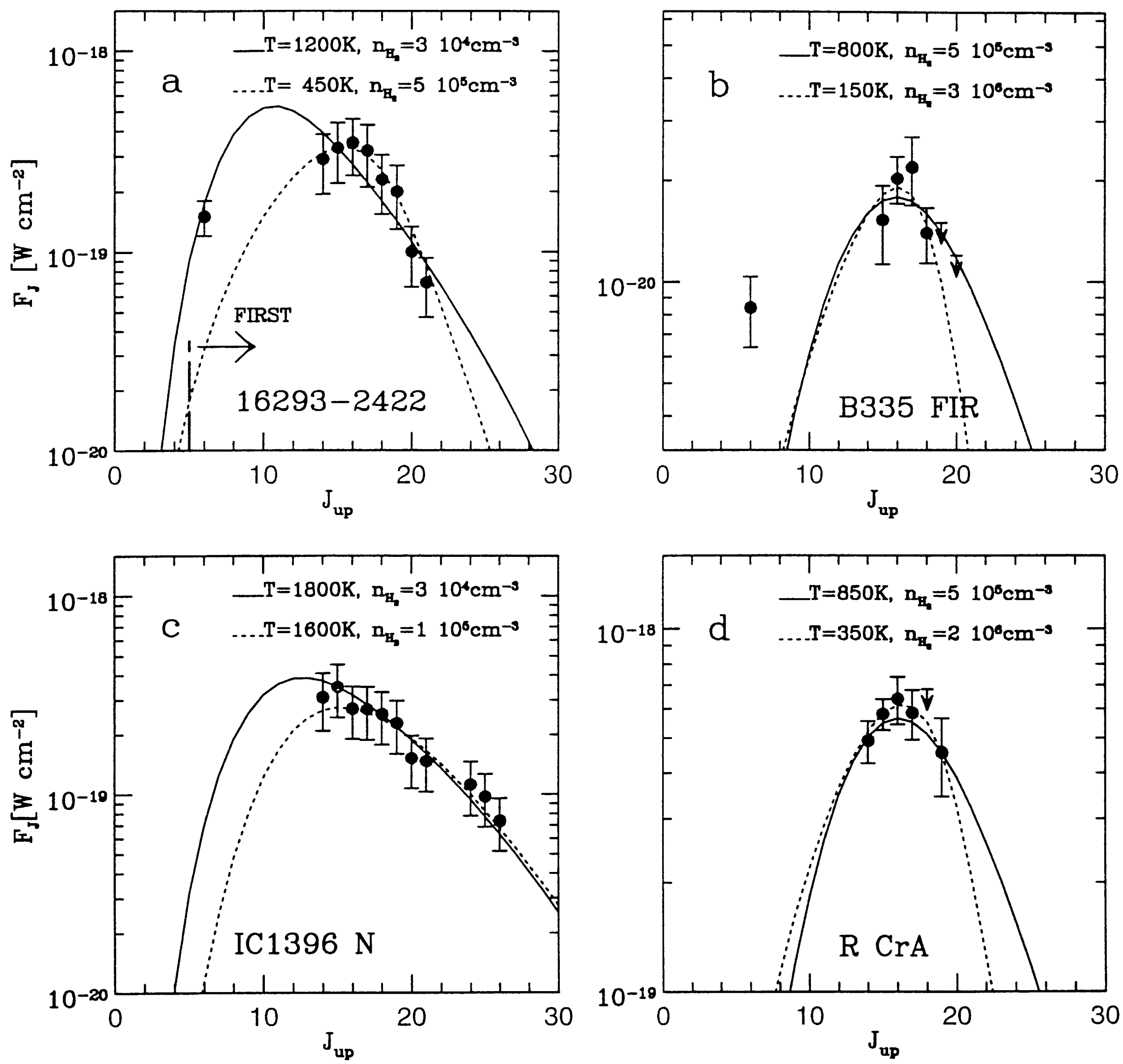

Figure 1. Figure 1: the CO line fluxes observed by ISO-LWS are plotted as a function of the rotational quantum number J_{up} for the four YSOs IRAS16293-2422 (a), B335 FIR (b), IC1396 N (c) and R CrA (d). Also plotted are the ground-based observations of the CO 6-5, when available. For each source, the continnum and dotted lines give the range of possible model fits through the observations. In Fig. 1a, the range of transitions that will be observed by the FIRST instruments is indicated.

in view of the fact that it is not always simple to reconcile the LWS observations with ground-based measures of lower J_{up} transitions assuming a single component gas emission. LWS observations alone cannot disentangle these different contributions: additional ground-based and space observations with a better spatial and spectral resolution are therefore particolary needed.

5. CONCLUSIONS

From the above discussion, we can summarize the possible rôle of the FIRST observations for better constrain the CO emission coming from YSOs:

- the three FIRST instruments in their spectroscopic modes are able to trace CO emission from $J_{up} = 5$ up to $J_{up} = 30$, thus enlarging the range observed by LWS and allowing to better constrain the physical parameters and define different emission components;
- HET will be able to resolve the profiles of the lower J_{up} CO lines, from which kinematical information on the different components can be derived;
- also the better spatial resolution with respect to the single ISO-LWS beam (a factor 5 at all the wavelengths), will be important to better localize the emission and have less problems of confusion.

We can conclude that FIRST will be certainly a great step forward to constrain current models of energetic flows from YSOs.

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